Charleston Bridge GPS Height Modernization Project

Using GPS, sensors will determine the maximum height of a vessel at the lowest point of a bridge. This project plan is for measuring the vertical clearance for the Cooper River Bridges. The vertical clearance is critical for ensuring safe navigation for the Port of Charleston.

Contents

Project Instructions

MEMORANDUM FOR: Edward E. Carlson
Team Leader, Charleston Bridge Project

FROM: Charles W. Challstrom
Acting Director, National Geodetic Survey

SUBJECT: INSTRUCTIONS: Charleston Bridge Project
Task Numbers: 8K6D5000 (HEIGHT MODERNIZATION)

GENERAL:

The National Geodetic Survey (NGS), Oceanographic Products and Services Division (OPSD) and the Coast Survey (CS), in accordance with NOAA's goal to Promote Safe Navigation and the Physical Oceanographic Real-Time System (PORTS) are working toward implementation of real-time, using GPS, sensors that will determine the maximum height of a vessel at the lowest point of a bridge. This project plan is for measuring the vertical clearance for the Cooper River Bridges, known as the Grace Memorial Bridge and Silias Pearman Bridge. The vertical clearance is critical for ensuring safe navigation for the Port of Charleston.

The project consists of 4 different parts as follows:

1. Determine the ellipsoid height of the two bridges using three different GPS receivers on the two bridges, one receiver at the pilot house, and a CORS site.
2. Determine the difference between Geoid96 with NAVD 88 by observing a minimum of four NAVD 88 bench marks including one primary bench mark at the tidal station.
3. Determine the height from the bottom of the bridges to each of the antenna mounts on the bridges using classical and trig leveling.
4. Perform a pseudo-kinematic survey of at least three NAVD 88 bench marks that includes the primary tidal bench mark station to demonstrate the capabilities of GPS to determine relative heights at tidal stations. (Note this will be done only if time permits.)

SPECIFICATIONS:

Project requirements for the GPS bridge observations are to ensure 2-centimeter local accuracy in the horizontal component, as well as 2-centimeter local accuracy for the ellipsoid heights.

Data from the Charleston (char1) CORS in the region are to be used in the processing. Position and data are available from the NGS web site.

General specifications for the project are as follows.

1. The observations on the two bridges consist of seven to thirty days of continuous operation.
2. Observing a minimum of three bench marks and one bench mark at the tidal station for at least two one-hour sessions. The observing scheme shall be arranged so that the start time of one observing session shall be at least 4 hours different than the other one. This ensures different atmospheric conditions (different days) and significantly different satellite geometry (different times) for the two base line measurements. Fixed-height tripods are required for all the receivers.
3. Special trig leveling procedures will be used to determine the height from the antenna mounts to the bottom of the two bridges.

The project will be performed under the technical management of NGS, OPSD, and CS with NGS providing the overall coordination.

In general, station occupation and observing procedures must be carried out according to appropriate sections of the "NGS Operations Handbook" and the current applicable receiver field manuals. Data formats and digital file definitions are given in "Input Formats and Specifications of the National Geodetic Survey Data Base," Volume I. Horizontal Control Data, Federal Geodetic Control Subcommittee, September 1994. Success in meeting the accuracy standards will be based on repeatability of measurements, analysis of loop misclosures, and adjustment residuals.

Data Acquisition - Data collection must be accomplished as specified in the appropriate dual-frequency receiver field manuals in the compressed mode at a 15-second epoch collection interval. The GPS receivers must be dual-frequency and full-wavelength. Track satellites down to a 10-degree elevation angle.

Record weather data if possible just before, immediately after, and at the mid-point of each session. Meteorological data shall also be collected immediately after an obvious weather front passes during a session and immediately before it passes, if possible. Pressure and relative humidity measurements must be made near and at about the height of the GPS antenna phase center. Indicate in the log the location of the barometer and psychrometer.

Survey operations shall be conducted with due regard to the safety of personnel and equipment.

Vector Computations - Data management, quality review of collected data, and final vector processing for the bridge survey will be accomplished by the NGS using PAGE4 and OPSD using Ashtech program "Ashtech Office Suite for Survey".

NGS will process the vectors observations on the two bridges consisting of seven to thirty days. The vectors shall be computed in the International Terrestrial Reference Frame (ITRF) system, using the most current epoch and precise IGS ephemerides. Use 30-second epoch intervals for data processing. Antenna reference point (ARP) positions will be used for the CORS. For stations where weather data are not available, or are suspect, predicted values computed based on the station's latitude, height above mean sea level, and time and day of year will be used. Use 15 degrees as the cutoff elevation angle in data processing. A cutoff angle of 10 degrees may be used when necessary to improve results.

In general, vectors greater than 5 km in length are to be computed in an ion-free fixed, or partially-fixed, solution. In all cases, integer ambiguities will be fixed for each vector whenever possible.

For each set of CORS reference marks, the CORS antenna at the site will be used as the reference station in the data processing.

The quality of collected data shall be determined from the plots generated from PAGE4, by analysis of repeated vectors and/or comparison of station positions, and free adjustment residuals and/or loop misclosures.

OPSD using "Ashtech Office Suite for Survey" with the guidance of NGS will perform the vector processing of all the GPS bench mark ties and all quality checks for conformance with NGS format standards such as executing software programs COMPGB, OBSCHK, and OBSDES. The final ITRF vectors will be assessed and transformed to the NAD 83 coordinate system using program ADJUST.

The type of final solution, L1 versus ion-free, will depend on the length of the vectors. For vectors which are less than 5 km in length, the final reduction will consist of a L1 fixed solution.

The all the data and results from NGS and OPSD will be submitted to the Observation and Analysis Division. All B-files and G-files must be complete, including *25* and *27* records.

Station Descriptions - Station recovery notes must be submitted in computer-readable form using DDPROC software. Include the name, address, and telephone number of a property owner or other contact.

Special Requirements - Antenna set-up is critical to the success of this project. Fixed-height tripods will be used for all receivers. The plumbing bubbles on the antenna pole of the fixed-height tripod must be shaded when plumbing is performed. They must be shaded for 3 minutes before checking and/or re-plumbing. Also, the perpendicularity of the poles must be checked at the beginning of the project and any other time there is suspicion of a problem.

A rubbing of the stamping of the mark must be made at each visit to a station. If it is impossible to make a rubbing of the mark, a plan sketch of the mark must be substituted, accurately recording all markings.

For each station visited, a visibility obstruction diagram must be prepared and the TO-REACH description carefully checked for errors or omissions.

The following must be recorded at each occupation of a station:

(1) receiver manufacturer,
(2) antenna manufacturer,
(3) receiver model number (part number),
(4) antenna model number (part number),
(5) the complete serial number of the receiver, and
(6) the complete serial number of the antenna.

Success of this project requires that the highest quality GPS data be collected. Therefore, during each station occupation, the operators shall carefully monitor the operation of the receivers. Any irregularities in the data due to equipment malfunction, DOD adjustment of the satellite orbit, obstructions, etc., must be reported to the team leader, as soon as possible and noted on the observing log. If the quality of observations for an observing session is questionable, notify the team leader immediately.

GPS DATA:

Visibility tables and plots of the present satellite constellation for February 2, 1999 through February 7, 1999 have been reviewed and the observations can be performed at any time of the day. For operational use, current data must be generated with Trimble, Ashtech mission planning software or from program SATMAP.

Project report and data listed in Annex L of "Input Formats and Specifications of the NGS Data Base" and in the attached addendum for the adjustment portion must be transmitted. Any data considered suspect as to quality in achieving accuracy standards should be sent via FedEx immediately for office review. Backup of transmitted data must be held until notified by Edward Carlson at the Project Development Branch, N/NGS21.

The data set collected during the project shall be named "scbr029a.086". All records in connection with this project shall be titled "CHARLESTON BRIDGE PROJECT, 1999". The project number (accession number) is GPS-1368.

LEVELING DATA:

Leveling data will be submitted in "Blue Book" format (see "Input Formats and Specifications of the National Geodetic Survey Data Base," Volume I. Horizontal Control Data and Volume II. Vertical Control Data, Federal Geodetic Control Subcommittee, September 1994) to Project Development Branch of NGS on floppy disks. Floppy disks shall contain the final version of the following files: HGF, HGZ, and HA in direct access format and RPT and ABS in sequential format. Data shall be submitted within 30 days of completion of the project.

All bench marks established and/or recovery bench marks descriptions shall be written in accordance with the "Blue Book" (unified descriptions), except do not submit incomplete descriptions (i.e. descriptions with Recovery Type Codes of "RM"), unless the bench mark is destroyed or not recovered.

LIAISON:

Liaison must be maintained with designated offices at the National Geodetic Survey headquarters located at:

1315 East-West Highway
Silver Spring, Maryland 20910-3282

Questions and problems concerning survey field operations, adjustment processing, and vector processing should be directed to:

Edward E. Carlson
Project Development Branch
N/NGS21
Telephone: 301-713-3196, ext. 108
Fax: 301-713-4316 or 301-713-4324
e-Mail: edc@ngs.noaa.gov

Questions and problems concerning using CORS data in processing should be directed to:

Neil Weston
Geosciences Research Division
N/NGS6
Telephone: 301-713-2847, ext. 202
Fax: 301-713-4475
e-Mail: nweston@ngs.noaa.gov

Questions and problems which could affect the technical adequacy of the project should be directed to:

Edward E. Carlson
Project Development Branch
N/NGS21
Telephone: 301-713-3196, ext. 108
Fax: 301-713-4316 or 301-713-4324
e-Mail: edc@ngs.noaa.gov

For tide site information, contact:

Brooks Widder
Oceanographic Products and Services Division
Requirements and Engineering Branch, N/CS41
Telephone: 301-713-2902, ext. 184

The contact for the project is:

Commander John D. Wilder, NOAA
Navigation Advisor for SE United States
Telehone: 843-740-1236
e-Mail: John.Wilder@noaa.gov

Names and telephone numbers of local contacts are given in the station description material.

PUBLICITY:

See "NGS Operations Handbook," Section 1.4.1.

EXPENSES:

Expenses for this project will be charged to task number 8K6D5000.

TRAVEL:

Travel and per diem are authorized in accordance with Federal Travel Regulations, Part 301-7, Per Diem Allowances. Current per diem rates were effective January 1, 1999.

ACKNOWLEDGMENT:

Please acknowledge receipt of these instructions in your Monthly Report.

Attachment

cc:
N/CS - N. Prahl*
N/CS - R. Barazotto*
N/CS3 - J. Wilder
N/CS4 - J. Dixon*
N/CS41 - B. Widder
N/CS42 - J. Oyler
N/NGS - S. Misenheimer*
N/NGS - D. Zilkoski*
N/NGS1 - G. Mitchell*
N/NGS11 - S. Cofer*
N/NGS11 - A. Murray
N/NGS2 - J. Till*
N/NGS21 - S. Frakes*
N/NGS21 - E. Carlson
N/NGS22 - T. Soler*
N/NGS3 - E. Allen*
N/NGS4 - E. Wade*
N/NGS5 - R. Snay*
N/NGS6 - N. Weston*
FGCS Members*

* first page only

DATA TO BE SENT TO HEADQUARTERS RELATING TO THE ADJUSTMENT PORTION OF THE PROJECT

Note that all except specified files or listings can be paper printouts or ASCII files on disk; be sure to keep backups until notified that the data base is loaded.
Free adjustment.
[For A- and B-order projects, the data are not scaled. First- order projects would also have a free adjustment using the modified G-file.]
Constrained horizontal adjustment holding previously published A- and B-order stations and ellipsoid heights (optional).
Constrained vertical adjustment holding NAVD 88 heights.
Final combined Blue Book file (ASCII required).
Free adjustment with accuracies.
Accuracy listing (output of BBACCUR). (Paper required).
ELLACC output.
OBSCHK output*.
CHKDESC output*.
OBSDES output*.

*any errors or warning messages must be explained.

Copies of data used to determine fixed control, both horizontal and vertical.
Final description file (ASCII required).
Final G file (ASCII required).

Project Implementation Plan

CHARLESTON BRIDGE PROJECT

BACKGROUND

A meeting was held in Charleston, South Carolina, to develop a project plan for measuring the vertical clearance for the Cooper River Bridges, known as the Grace Memorial (older bridge) and the Silas Pearman (newer bridge). This measurement is critical to ensuring safe navigation for the Port of Charleston.

This is the first step towards implementation of real-time, using GPS, sensors that will determine the maximum height of a vessel at the lowest point of the Cooper River Bridges. This follows NOAA goal to Promote Safe Navigation. A timely response is extremely critical to this problem for navigation since a ship recently struck the Silas Pearman bridge.

Preliminary meetings were held in Charleston, South Carolina, with the following in attendance:

1. Captain Russell Woodill, Maritime Association Port of Charleston.
2. Commander Bob Bennett, Marine Safety Office, U.S.C.G.
3. Mr. J. Wesley Timmerman, South Carolina Department of Transportation
4. Commander John Wilder, NOAA/ NOS/CS
5. Mr. David Zilkoski, NOAA/NOS/NGS
6. Mr. Jim Dixon, NOAA/NOS/OPSD.

During the meeting the following scenarios were discussed:

1. Two GPS receivers on the older bridge for 1 week
2. One receiver on the newer bridge for 1 week
3. Threes GPS receivers on the older bridge for 30 days
4. One GPS receivers at the tidal station for 37 days

It was finally decided that two GPS receivers would be on the newer bridge, one receiver on the old bridge, and one receiver at the pilot house.

Preliminary schedule is as follows:

1. SCDOT provide NGS drawing of bridges by 11/30/1998 - DONE
2. NGS/OPSD/SCDOT conduct full site reconnaissance by 12/11/1998 - DONE
3. Finalize project plans NGS/OPSD by 01/15/99 - DONE
4. Conduct Static Measurements during 01/15/99 to 02/28/99 changed to 02/04/99- 03/05/99
5. One sensor to remain in place 03/05/99 to 03/31/2000

The following will do the following for the project:

1. NGS and OPSD will do the necessary field work.
2. SCDOT will provide guidance and or perform the climbing on the bridge.
3. SCDOT will provide for the electrical power required on the bridges.
4. NOS will provide the DGPS and associated radios and computer equipment.
5. Pilot Association pilot house will provide space, AC power, telephone service and security for the base station.
6. Charleston Center's will provide the T-1 communication lines.

PHASES

1. Position the bridges observing with three different receivers on the bridges, one at the pilot house and a CORS site (CHA1). Observations will be 1 week to 30 days. (CORS plus 4 receivers)
2. Perform two one hour (min) sessions observing three NAVD88 bench marks plus one primary tidal station (bench mark). One session will be in AM of day 1 and PM of day 2. (CORS plus 4 receivers at min., working on getting one more receiver to co-observe at the pilot house at the same time.)
3. Leveling observations to determine the height of the bottom of the bridge to each of the antenna mounts.
4. Do a psuedo-kinematic survey of at least three NAVD88 bench mark between the primary tidal station and another bench mark from phase 2. (Note this will be done only if time permits.)

RESULTS

1. All GPS observations will be blue booked and adjusted and loaded into the NGS data base.
2. All leveling observations will be blue booked and loaded into the NGS data base.
3. There will be a relationship between the ellipsoid heights and water level values.
4. It will be training for OPSD (FOB & REB) groups on planning, observing, processing and doing adjustments of GPS-derived ellipsoid and orthometric height projects to 2 cm and 5cm.
5. There will be GPS-derived height for the bottom of the bridge and leveled height of the bottom of the bridge to compare results.

RESPONSIBILITIES

The following responsibilities and assignments were determined during the meeting held on January 7, 1999 at NGS with the following people present, from NGS; Edward Carlson, Bill Rindal, David Crockett, David Crump, Audie Murray, and David Zilkoski, from OPSD; Jeff Oyler, Brad Winn, Brooks Widder.:

1. Determining the height of the bridge, bottom to antenna mount - Murray, Rindal, Crockett
2. GPS observations - Carlson, Oyler, Wynn, Widder
3. Installing the GPS equipment and gathering the GPS data on the bridges and the pilot house - Crump, Maron
4. Any leveling needed to be done - Crockett, Murray, Rindal, Carlson
5. All vertical observations are blue booked, adjusted and loaded into the NGS data base - Murray,

Crockett
6. All GPS observations are processed, adjusted, blue booked and loaded into the NGS data base - Oyler, Carlson
7. Project coordinators - Carlson, Oyler

ASSIGNED TASKS

Jeff Oyler - will contact Cmdr. Wilder about contacting the Charleston Bridge DOT about the following:

1. lane closures on the two bridges, Wednesday, Feb 3 - southern most lane on new bridge; Thursday, Feb 4 - northern most lane on the old bridge; Friday, Feb 5- southern most lane on new bridge (if needed); Saturday, Feb 6 - northern most lane on old bridge (if needed).
2. Three days to install the GPS receivers on the two bridges after the trig leveling and bench mark GPS work is completed .
3. Supplying continuous 110 VAC power at the centerspan for the three receivers.

Brad Wynn - will find about lodging for the project. Design and procure bridge and pilot house antenna mounts.

Dave Crump - will let Edward Carlson know how much data can be stored on the FLASH CARD used in the receivers. Find two additional Ashtech antennas and one receiver which can be used for this project.

Audie Murray and Bill Rindal - will practice and determine the best method/procedures for determining the elevation at each antenna mounting plate, for profiling the span and methods to compute the elevation for the bottom of each bridge.

David Crockett - will investigate the bench marks which will be used for leveling to the new bench mark which will have to be set.

Dave Crump, Edward Carlson, Ernie Maron - will test each receiver at NIST.

Edward Carlson and David Crockett - will transport all the FOB GPS equipment to Charleston.

TENTATIVE CHARLESTON BRIDGE WORK SCHEDULE

AM PM

Monday February 1, 1999	Travel	Travel
Tuesday February 2, 1999	Finish RECON + set marks (Crockett, Carlson, Oyler, Widder) Set mounting plates on new bridge and install antenna cables (Crump, Murray, Rindal,Wynn) Set up base station at pilot house (Marion)	Static GPS observations on bench marks (Crockett, Carlson, Oyler, Widder) Mount antenna and cables at PILOT house (Crump, Murray, Rindal, Wynn) Set up base station at pilot house (Marion)
Wednesday February 3, 1999	Static GPS observations on BMs (Wynn, Carlson, Oyler, Widder) Trig leveling on new bridge (Crump, Murray, Rindal, Wynn) Set up base station at pilot house (Marion)	Psuedo-kinematic GPS on BMs around the tidal station (Wynn, Carlson, Oyler, Widder) Trig leveling on new bridge (Crockett, Murray, Rindal, Crump) Set up receivers on the new bridge (Marion, Crump, plus others)
Thursday February 4, 1999	Level new bench marks (Crockett, Carlson, Oyler, Widder) Trig leveling on old bridge (Crump, Murray, Rindal, Crockett)	Training on processing GPS data (Carlson, Oyler, Wynn, Widder) Trig leveling on old bridge (Crump, Murray, Rindal, Crockett) Set up receiver on the old bridge (Crump, plus others)
Friday February 5, 1999 (See note # 2)	Psuedo-kinematic GPS on BMs around the tidal station (Carlson, Oyler, Widder, Wynn) Trig leveling on new bridge (Crump, Murray, Rindal, Crockett)	Training on processing GPS data (Carlson, Oyler, Wynn, Widder) Trig leveling on new bridge (Crump, Murray, Rindal, Crockett) Set up receivers on the new bridge (Crump, plus others)
Saturday February 6,	Training on processing GPS data (Carlson, Oyler, Wynn, Widder)	Training on processing GPS data (Carlson, Oyler, Wynn, Widder)

1999 (See note # 2)	Trig leveling on old bridge (Crump, Murray, Rindal, Crockett)	Trig leveling on new bridge (Crump, Murray, Rindal, Crockett) Set up receiver on the old bridge (Crump, plus others)
Sunday February 7, 1999	Travel	Travel

NOTE 1 - Ernie Marion could return on Thursday morning.

NOTE 2 - When the trig leveling to determine the height of the bridge, bottom to the antenna mount, for all the antenna mounts on both bridges and the static GPS observations on the BMs is completed which could be as early as Friday or Saturday morning then Carlson, Crockett, Murray, and Rindal will travel home.Remember trig leveling could take longer than scheduled above because of weather conditions or the DOT which means that Rindal, Murray and Crump would have stay longer in Charleston.

Project Trip Leveling Report

COOPER RIVER BRIDGES PROJECT
CHARLESTON, SOUTH CAROLINA

Project Report

National Geodetic Survey
Instrumentation & Methodologies Branch
Corbin, Virginia

March 3, 1999

Report by:
Orland W.Murray, Geodetic Technician
William J. Rindal, Geodetic Technician

A. Location

Charleston, South Carolina at, on and in the vicinity of the Grace Memorial Bridge and the Silas Pearlman Bridge over the Cooper River (U.S. Highway 17).

B. Scope

1. Purpose.

This project was a joint efort by the National Ocean Service's Oceanographic Products and Services Division (OPSD), the Coast Survey, and the National Geodetic Survey's (NGS) Instrumentation & Methodologies Branch (I&M Branch) in accordance with NOAA's goal to Promote Safe Navigation and the Physical Oceanographic Real-Time System (PORTS). The objective is to develop a real-time system using GPS to determine the maximum height of a vessel at the lowest point of a bridge. Two bridges over the Cooper River in Charleston, S.C., the Grace Memorial and Silas Pearlman, are the subject of this project.

The task of the I&M Branch was to determine the physical height of the bottom of the bridges below three GPS antennas (two on the Silas Pearlman bridge and one on the Grace Memorial bridge) and determine orthometric heights (elevations) of the antennas and various points (profiles) along the bottom of the bridges to a minimum of 150 feet out on both sides of the centerline of the bridges over the shipping channel. Accomplishment of these tasks was to be done employing special trigonometric leveling techniques developed by the I&M Branch.

2. Specifications.

To determined height differences and elevations to a 2 centimeter or less accuracy.

3. Monumentation.

A new bench mark was set on each of the bridges to serve as a starting reference for future surveys should they occur. These stations were SILAS 1999 on the Silas Pearlman bridge and GRACE 1999 on the Grace Memorial bridge. Each was set in the bridge highway curb near the centerline below the GPS antenna reference points (ARP).

The GPS antenna references points on the Silas Pearlman bridge consisted of aluminum angle brackets bolted to safety railing uprights at the top of the bridge. One on the north side and one on the south side of the bridge. These should be considered semi-permanent. The ARP on the Grace Memorial bridge consisted of a special tribrach with 3 magnetic feet. This was mounted on a horizontal gusset plate at the top of the bridge and secured with tie down cables. This should also be considered semi-permanent.

Recoverable temporary points were established on both bridges. These were SILAS TP1 and GRACE TP1 and were described and marked but not monumented. Both were the top of flat sturdy metal railings that allowed easy attachment of a trig-leveling target mounted on a three inch magnet base.

Non-recoverable temporary points were created to transfer heights to the bottom of the bridges at the centerlines and along the tops of the beams at the bottom of the bridges for the profile observations.

4. Instrumentation. (See Equipment List - ATTACHMENT C)

Primary instrumentation was a Leica TC2002 Total Station providing high accuracy in horizontal (0.5"), vertical (0.5"), and distance measurements (+\-1 mm + 1 ppm). Other equipment used with it were various retro-prism targets, target supports, and range poles. These various components of equipment were tested and calibrated prior to the project.

C. Comments

1. Reconnaissance and Planning

A special reconnaissance trip was taken to Charleston a month earlier than the project to determine location of the GPS antennas, recover local horizontal and vertical control stations, and determine how the heights of the bottom of the bridges might be measured.

After study and evaluation of the information and pictures gathered from the reconnaissance trip, several methods for measuring the height difference between the GPS antennas mounted on top of the bridges and the bottom of the bridges were tested at the I&M Branch facility in Corbin, Va.

The methods tested consisted of trigonometric leveling, remote height measurments, vertical electronic distance measurements (EDMI), and vertical taping. Trig leveling appeared to the most expedient method followed by remote height measurements (a variation of trig-leveling where the distance is measured to a point below the unknown height point), and finally vertical EDMI distances. The last two methods would require a way to collimate directly below the GPS antenna locations. At the time of the tests, it was not known if this would be possible. Vertical taping was a last resort method if none of the others were possible. The only significant unknown affecting the methods involving the use of the total station instrument was the effects from vibration and movement of the bridges due to traffic.

2. Specifications and Procedures.

The first day on the Silas Pearlman bridge an experiment was conducted to test the leveling compensators of the total station. The results were very close with this function turned on and off. However, with it on, the constant traffic induced vibration made the spreads large in the difference of elevation measurements. The compensators were turn off and the instrument kept level manually. A little time was lost at each setup, but otherwise this worked ok. With this problem resolved, the measurements could be started.

Height Differences Using Trig-leveling

Height differences using trigonometric leveling is accomplished by measuring a zenith distance angle and a slope distance to a target forming a right triangle. The base of the triangle is through the vertical center of rotation of the total station instrument (TSI). The slope distance is the hypotenuse and 90 degrees minus the zenith distance is the angle at the intersection of the base and hypotenuse. Given these values, the length of the opposite side of the right triangle can be solved for yielding the height difference between the target and the vertical center of rotation of the TSI. Calculation of the height difference is performed by on-board software stored in the instrument and the value is shown in one of the LCD display windows. It can also be recorded to an on-board data storage recording module. Previous testing of this function has proven its validity when compared to computing the height outside the instrument.

Corrections Applied to Trig-leveling

Prior to observing the measurements, both meteorological data (air temperature and pressure) and instrument and prism offset constants values must be stored into the instrument. The met data is used to compute the refractive index correction of the atmosphere for the EDMI being used. The instrument and prism offset constants were determined by calibration prior to the project. These values are stored in the TSI as a parts per million (PPM) correction from the met data and a combined offset constant (in millimeters) for the EDMI and retro-prism being used.

Also, a standard correction for curvature and refraction is applied to each height difference measurement based on the following formula:

Height Difference = (SD*COS(ZD))+(1-k/2R)*(SD*SIN(ZD))2
where: k = 0.13 (mean value for coefficient of refraction) R = 6.37*10E6 meters (earth radius), SD = measured Slope Distance , ZD = measured Zenith Distance

This correction is also performed by the TSI's on-board software.

Height Difference Determination

The height difference or difference of elevation (d.e.) between two points is obtained by first measuring to a backsight (BS) target which gives the d.e. from the target to TSI. Next, a measurement is taken to a foresight (FS) target which gives the d.e. from the target to the TSI. The foresight d.e. minus the backsight d.e. yields the height difference with the correct sign between the two targets. The relationship of the target to the point to which the height difference is to be established must be considered and appropriate corrections made. In most cases, if both the BS and FS targets are of equal height above the respective points, then the resulting d.e. between the targets is the d.e. between the two points. In other cases, as in this project, corrections for the physical height of the target above or below a reference point must be applied. Figure #1 in ATTACHMENT A illustrates how the height difference from the GPS antennas on top of the Silas Pearlman bridge to reference point Silas TP1 was determined for this project. This case required corrections for both of the targets. Figures #2 and #3 in ATTACHMENT A illustrate the more common scenario where both targets are of equal height above the elevation points. This method was used to measure the height difference from the GPS antenna on top of the Grace Memorial bridge to the Grace TP1 reference point. Figure #3 depicts how the height differences were transferred to the bottom of the bridges at the centerlines and for the profiles.

For all of the height transfers from the antennas down to the bottom of the bridges, multiple measurements from 5 to 10 or more were taken in both direct and reverse positions of the TSI. The average of these was used as the final difference of elevation. For the profile measurements, a minimum of two sets (1 set = direct/reverse on each target) were taken.

Elevation Ties to Local Vertical Control

Once the height differences on the bridges were established double run trig-leveling was run from BM R16 to BM Y151 to reference mark SILAS 1999, and finally to BM X151. Elevations were transferred to the Grace Memorial Bridge through BMs Silas 1999 to Silas TP1 to Grace TP1 using trig-leveling. Observations were made from each bridge to the other on two different days.

D. Closures and Field Checks

1. Blunder checks

These measurements were by no means very precise but provided an in the ball park check on the trig-leveling measurements.

a. Silas Pearlman Bridge

The height from SILW ARP (Silas West Antenna Reference Point) to Silas TP1 was measured with a tape. This was not a perfectly vertical measurement, but close. A reasonablely good check was made.

Taped height ....: -45.8 ft.
Trig-level height: -45.7 ft.

Difference: 0.1 ft. (1.2 inches)

b. Grace Memorial Bridge

Prior to this project the South Carolina Dept. of Transportation (SCDOT) measured the height of the Grace Memorial bridge at the centerline upright of the bridge (midspan at U22 L22 chord to chord). The trig-leveling height measured was from the top edge of the horizontal gusset plate on which the antenna was mounted to the bottom edge of the horizontal gusset plate at the bottom of the bridge. SCDOT did not show us exactly where they measured from and to and we forgot to have them show us. The difference is larger than hoped for.

Trig-levels height: -63.96 ft
SCDOT taped height: -63.55 ft

Difference: 0.41 ft (4.92 inches)

2. Leveling Closures

A line tie was made from several bench marks to the east of the bridges and through several bench marks at the east end of the bridges. Double Run Trig-leveling was used from BM R16 (east end of Grace Memorial bridge) to Y151 (east end of Silas Pearlman bridge) to Silas 1999 (on Silas Pearlman bridge) to X151 (also on Silas Pearlman bridge). A new minus old comparison was done between previous First Order leveling (1979) and the current trig-leveling. Since Silas 1999 was new mark between Y151 and X151, the difference of elevation (d.e.) between Y151 and X151 was computed using the sum of the d.e. from Y151 to Silas 1999 and the d.e. from Silas 1999 to X151.

R16 to Y151
Published NAVD88 elevation R16 .... = 3.1810 m
Published NAVD88 elevation Y151 ... = 8.3473 m
Difference of elevation .... = 5.1663 m

R16 to Y151 trig observed d.e. .... = 5.1661 m
R16 to Y151 published NAVD88 d.e... = 5.1663 m
New-Old. = -0.0002 m

Y151 to X151
Published NAVD88 Elevation X151 ... = 42.6961 m
Published NAVD88 Elevation Y151 ... = 8.3473 m
Difference of elevation .... = 34.3488 m

Y151 to Silas 1999 trig observed... = 41.0962 m
Silas 1999 to X151 trig observed... = -6.7459 m
Y151 to X151 trig-leveling observed = 34.3503 m
Y151 to X151 published NAVD88 d.e.. = 34.3488 m
New-Old = 0.0015 m

3. Summary of Individual Height Measurements (See sketches in Attachment B showing location of points)
a. Silas Pearlman Bridge
SILE ARP to Silas TP1
Silas TP1 to SILE CL
SILW ARP to Silas TP1
Silas TP1 to SILW CL
Silas TP1 to Silas 1999
Silas 1999 to Profile Points 1-16
Silas TP1 to Grace TP1

b. Grace Memorial Bridge
Grace TP1 to Silas TP1
GRAC ARP to Grace TP1
Grace TP1 to Grace CL

Grace TP1 to Grace 1999
Grace 1999 to Profile Points 1-10

c. Leveling Ties (Double-Run Trig-Levels)
R16 to Y151
Y151 to Silas 1999
Silas 1999 to X151

E. Recommendations

Despite the constraints of limited time and persistent traffic on the bridges, the results of this project are very good. It appears that heights and elevations determined using trig-leveling techniques fall within about a centimeter or less. This is well within the 2 centimeters desired. All objectives were met.

1. Determine the physical height of the bottom of the bridges below three GPS antennas.
2. Determine orthometric heights (elevations) of the antennas and various points (profiles) along the bottom of the bridges to a minimum of 150 feet out on both sides of the centerline.

For similar future projects, the use of trig-leveling techniques should provide a viable means for height transfers if the following procedures are adhered to.

1. Use a total station instrument (TSI) with at least a 1 second or better angulation capability and an electronic distance measuring accuracy of +/- 3 mm + 2 ppm or better.
2. Be sure all parameters and corrections are dialed into the TSI correctly (i.e. temperature, pressure, offset constant corrections, and refraction/curvature correction on).
3. Keep height transfer sight lengths as short as possible (50 meters or less) and angle to upper target 45 degrees or less if possible.
4. Keep TSI as level as possible. Monitor instrument level often. In most cases, if bridge is shaky, it will not be possible to use TSI electronic leveling compensation.
5. Take 5 or more sets (1 set = 1 direct/reverse pointing) on each backsight and foresight targets.
6. Take two independent sets of measurements. Measure one set of 5, BS/FS, then reset the instrument and take another set of 5. This will constitute a forward and backward running providing some redundancy.
7. Keep good notes and sketches on target placement, heights above references points, reflector constants, for application to post observation computations.
8. If profiling bottom of bridge, double run between all points and carefully determine distance from centerline to each profile point.

Other Recommendations

It is not necessary to make a direct height measurement between two points of interest. Temporary points can be used as in the case of this project. To determine the height difference from the antenna reference points to the bottom of the bridge, four measurements had to be taken. SILE ARP to SILAS

TP1, SILAS TP1 to SILAS 1999, SILAS 1999 to Top of the Beam, and finally the thickness of the beam (See Attachment B Figure #3). The sum of these, after applying corrections, yields the final height difference. Choose temporary points that can be remeasured and are stable.

Stability is a key component of good survey measurements. In most normal environments, stability of the instrument platform is achieved. However, when working on bridges carrying traffic, movement of the bridges is inevitable and natural to the bridge design. So, if it is possible to set up on a stable platform (a pier, an island, another bridge) nearby, do so and make height transfers from there. Of course, the points of interest on the bridge must be visible from there.

Data collection for this project could have been better implemented. Although trig-leveling software had been previously developed, it needed modification to be applied to this projects specifications. The I&M Branch will address this for future application. This was not a major problem given that there was a small amount of data.

TABULATED ELEVATIONS AND HEIGHT DIFFERENCES

Antenna Reference Points to Bottom Centerline of Bridges

From Point			To Point			Height Difference	
SPSN	Designation	Elevation (m)	SPSN	Designation	Elevation(m)	Meters	Feet
0009	SILE ARP	65.2046	0010	SILE CL	46.5969	-18.6077	-61.0488
0008	SILW ARP	65.2104	0011	SILW CL	46.5903	-18.6201	-61.0894
0013	GRAC ARP	66.9055	0015	GRACE CL	47.3507	-19.5548	-64.1560

Antenna Reference Points to Bottom of Bridge Profile Points (South Side of Silas Pearlman Bridge)

From Point			To Point			Height Difference	
SPSN	Designation	Elevation (m)	SPSN	Designation	Elevation (m)	Meters	Feet
0009	SILE ARP	65.2046	0020	SILAS PF5	46.2159	-18.989	-62.300

0021	SILAS PF6	46.4376				-18.767	-61.571
0022	SILAS PF7	46.5052				-18.699	-61.348
0023	SILAS PF8	46.5941				-18.611	-61.050
0010	SILE CL	46.5969				-18.608	-61.049
0031	SILAS PF16	46.5900				-18.615	-61.073
0030	SILAS PF15	46.5761				-18.629	-61.119
0029	SILAS PF14	46.4372				-18.767	-61.571
0028	SILAS PF13	46.2126				-18.992	-62.310

Antenna Reference Points to Bottom of Bridge Profile Points (North Side of Silas Pearlman Bridge)

From Point			To Point			Height Difference	
SPSN	Designation	Elevation (m)	SPSN	Designation	Elevation (m)	Meters	Feet
0008	SILW ARP	65.2104	0019	SILAS PF4	46.2123	-18.998	-62.329
0018	SILAS PF3	46.3293				-18.881	-61.945
0017	SILAS PF2	46.4935				-18.717	-61.407
0016	SILAS PF1	46.5563				-18.654	-61.201
0011	SILW CL	46.5903				-18.620	-61.089
0024	SILAS PF9	46.5880				-18.622	-61.096
0025	SILAS PF10	46.4995				-18.711	-61.388
0026	SILAS PF11	46.4295				-18.781	-61.617

0027	SILAS PF12	46.2096				-19.001	-62.339

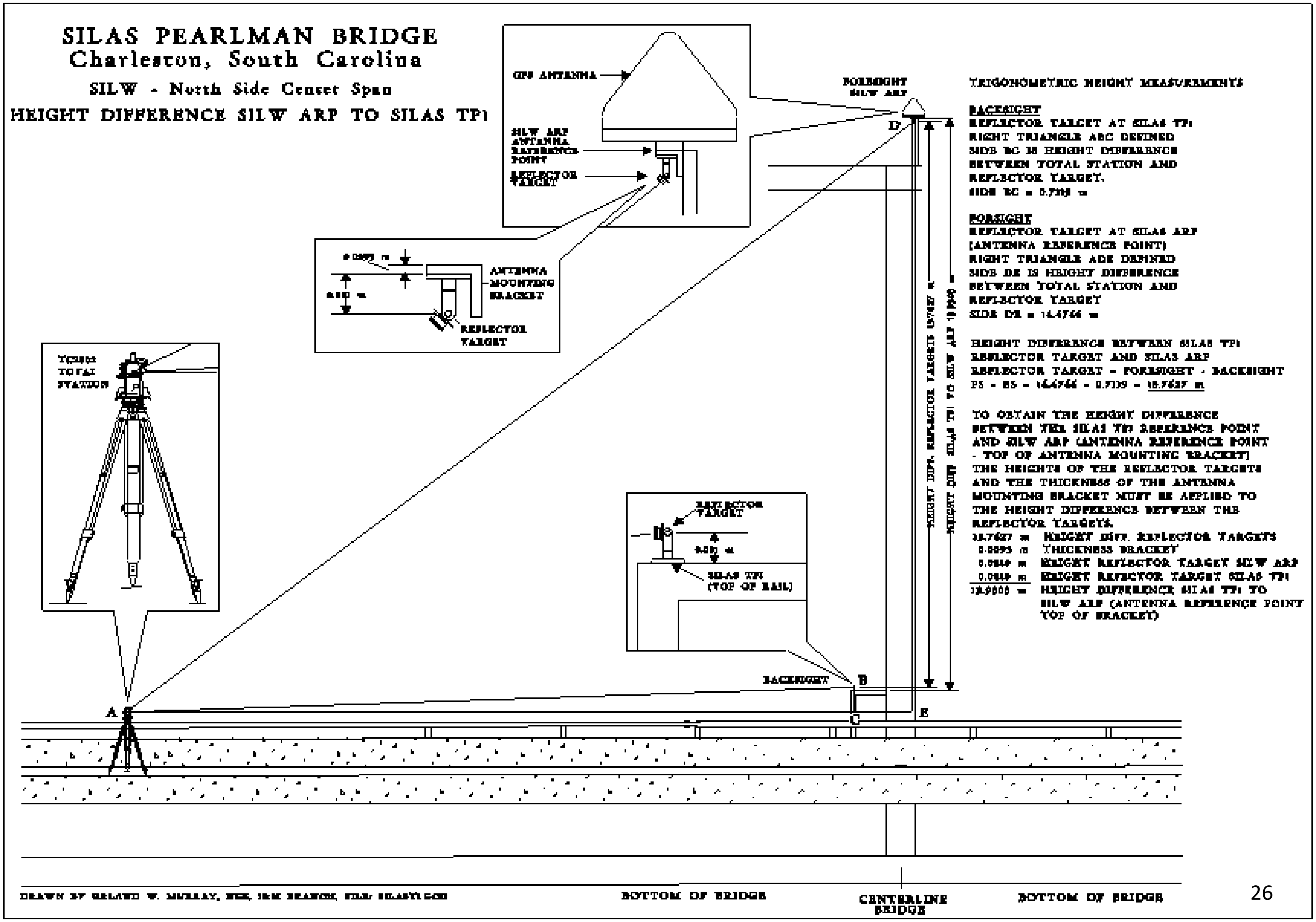
Antenna Reference Points to Bottom of Bridge Profile Points (North Side of Grace Memorial Bridge)

From Point			To Point			Height Difference	
SPSN	Designation	Elevation (m)	SPSN	Designation	Elevation (m)	Meters	Feet
0013	GRAC ARP	66.9055	0041	GRACE PF10	42.4869	-24.419	-80.113
0040	GRACE PF9	43.8047				-23.101	-75.790
0039	GRACE PF8	45.1317				-21.774	-71.436
0038	GRACE PF7	46.3189				-20.587	-67.541
0037	GRACE PF6	47.1003				-19.805	-64.978
0015	GRACE CL	47.3507				-19.555	-64.157
0032	GRACE PF1	47.3552				-19.550	-64.141
0033	GRACE PF2	46.8308				-20.075	-65.862
0034	GRACE PF3	45.7661				-21.139	-69.355
0035	GRACE PF4	44.4580				-22.448	-73.647
0036	GRACE PF5	43.1436				-23.762	-77.959

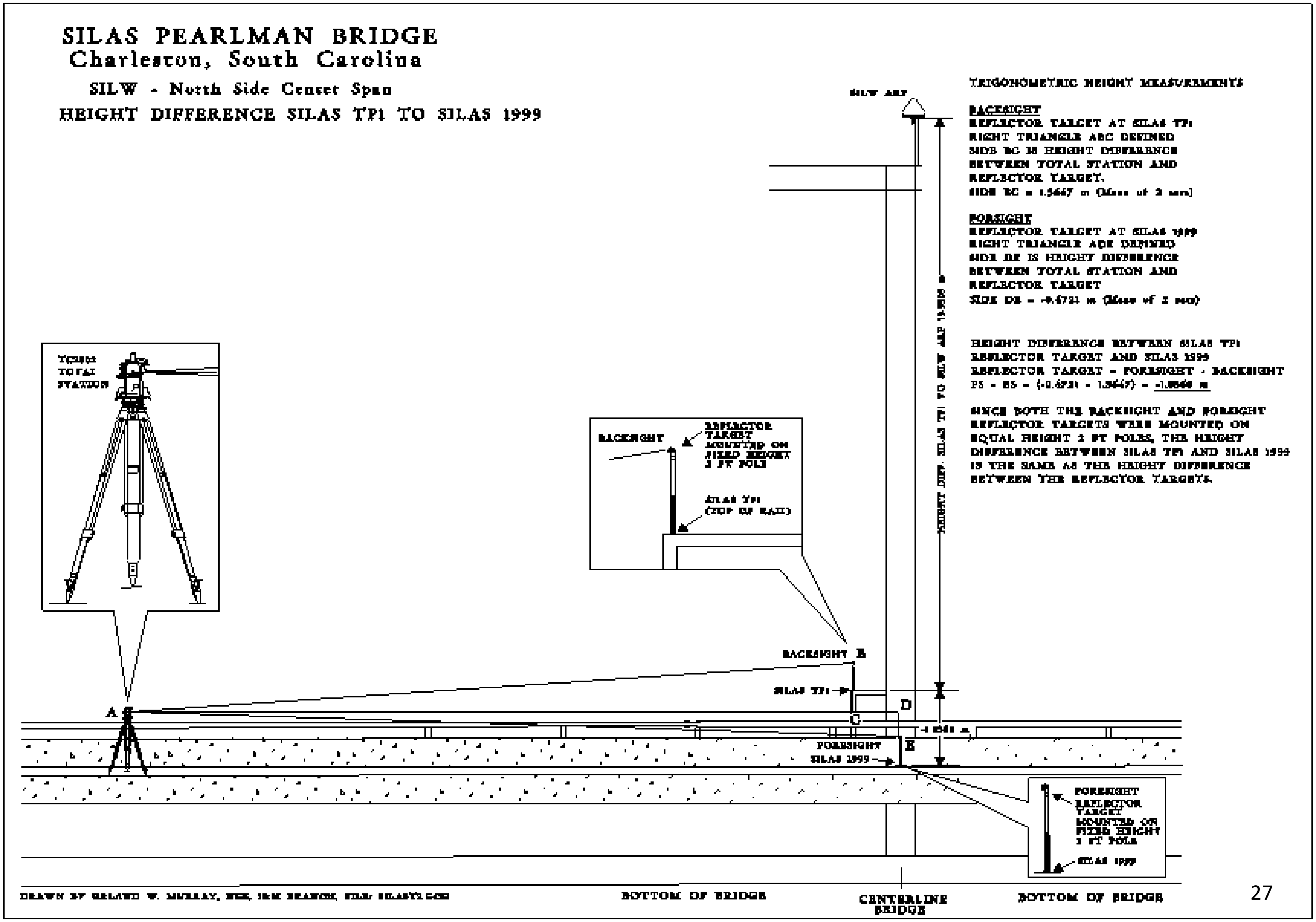
ATTACHMENT A

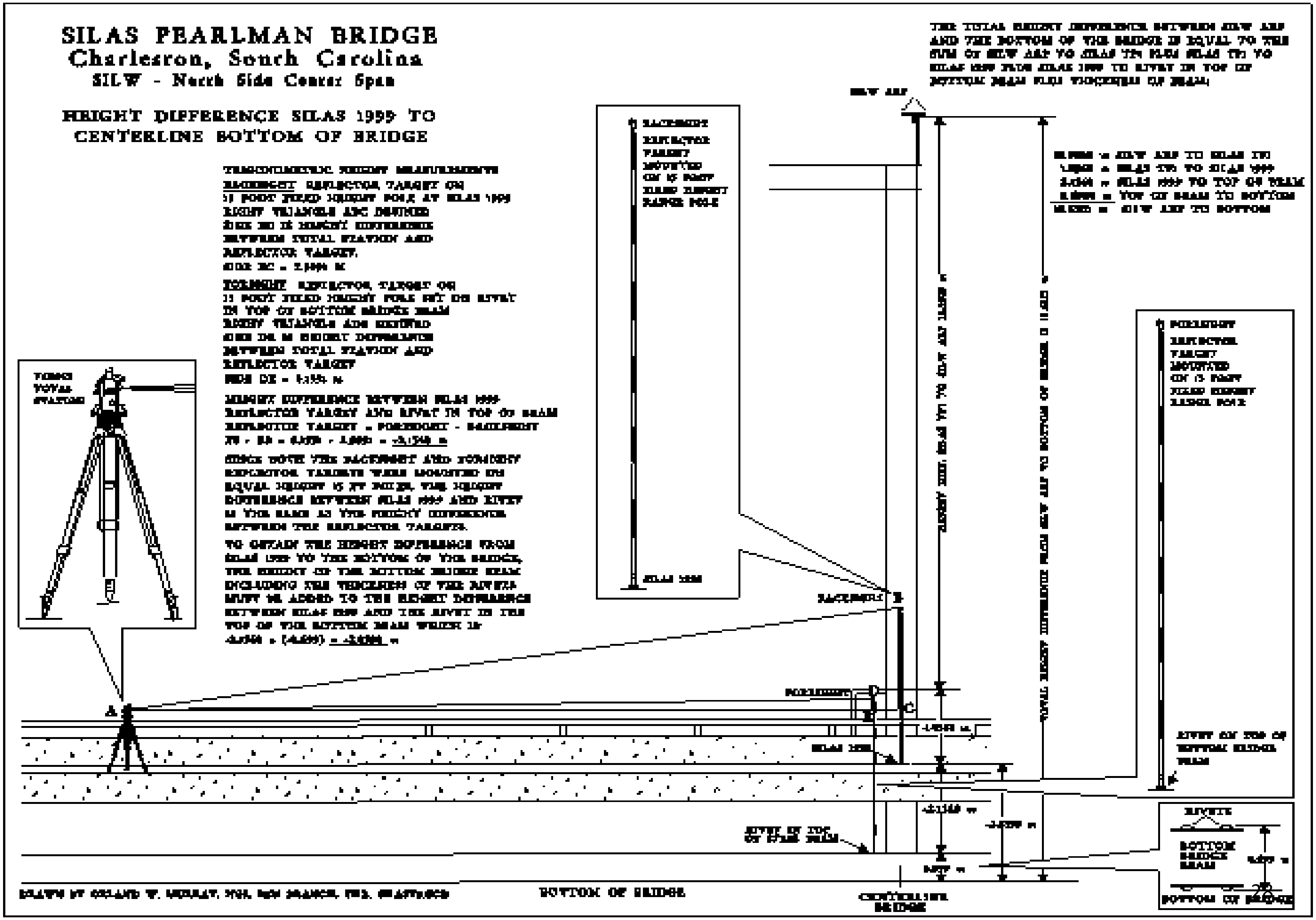
Trigonometric Leveling

Height Measurement Diagrams



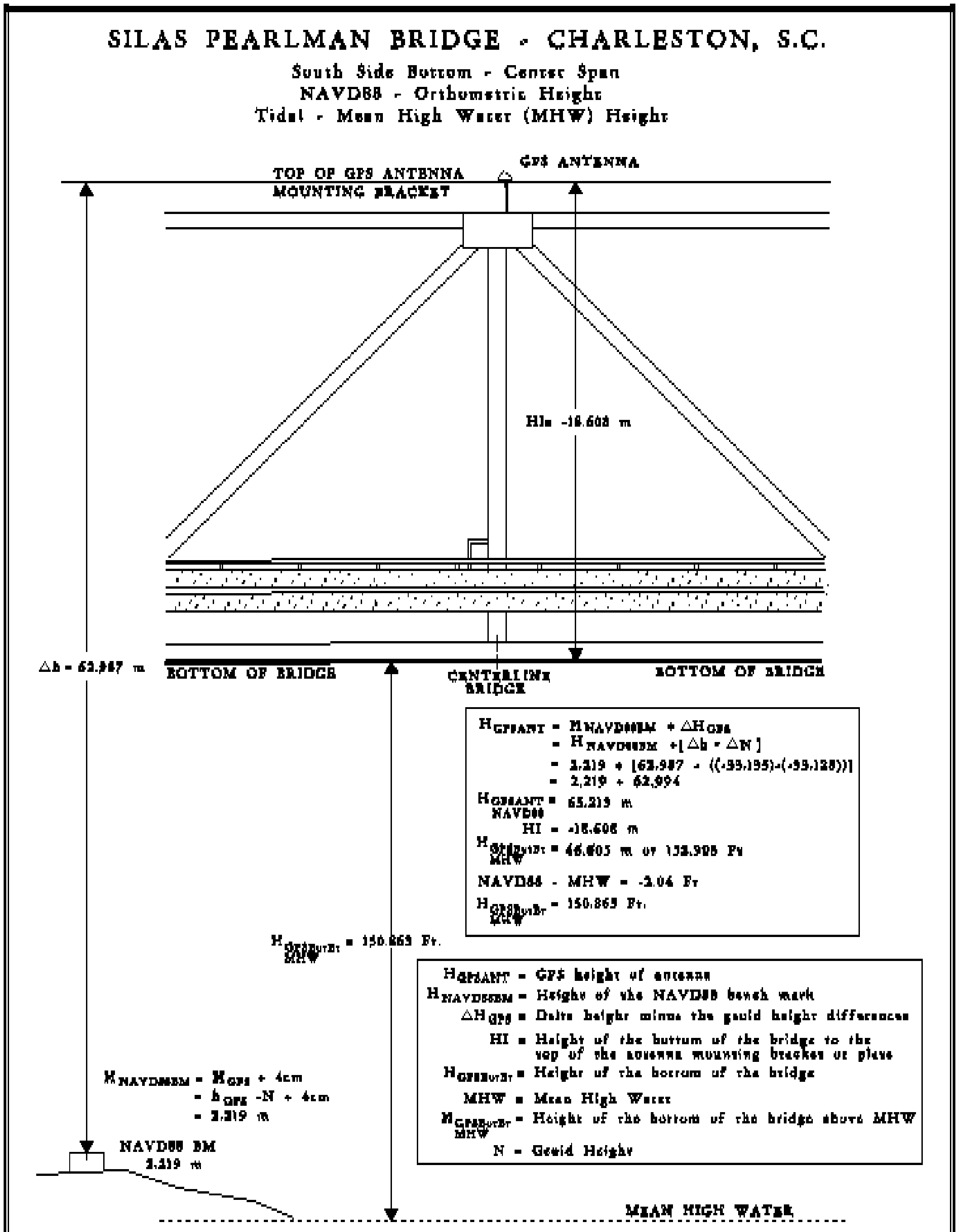
SILAS PEARLMAN BRIDGE
Charleston, South Carolina
SILW - North Side Center Span
HEIGHT DIFFERENCE SILW ARP TO SILAS TP1
GPS ANTENNA
SILW ARP ANTENNA REFERENCE POINT
REFLECTOR TARGET
ANTENNA MOUNTING BRACKET
REFLECTOR TARGET
TOTAL STATION
FORESIGHT SILW ARP
D
TRIGONOMETRIC HEIGHT MEASUREMENTS
BACKSIGHT
REFLECTOR TARGET AT SILAS TP1
RIGHT TRIANGLE ABC DEFINED
SIDE BC IS HEIGHT DIFFERENCE
BETWEEN TOTAL STATION AND
REFLECTOR TARGET.
FORESIGHT
REFLECTOR TARGET AT SILAS ARP
(ANTENNA REFERENCE POINT)
RIGHT TRIANGLE ADE DEFINED
SIDE DE IS HEIGHT DIFFERENCE
BETWEEN TOTAL STATION AND
REFLECTOR TARGET
SIDE DE = 14.4746 m
HEIGHT DIFFERENCE BETWEEN SILAS TP1
REFLECTOR TARGET AND SILAS ARP
REFLECTOR TARGET = FORESIGHT - BACKSIGHT
TO OBTAIN THE HEIGHT DIFFERENCE
BETWEEN THE SILAS TP1 REFERENCE POINT
AND SILW ARP (ANTENNA REFERENCE POINT
- TOP OF ANTENNA MOUNTING BRACKET)
THE HEIGHTS OF THE REFLECTOR TARGETS
AND THE THICKNESS OF THE ANTENNA
MOUNTING BRACKET MUST BE APPLIED TO
THE HEIGHT DIFFERENCE BETWEEN THE
REFLECTOR TARGETS.
HEIGHT DIFF. REFLECTOR TARGETS
THICKNESS BRACKET
HEIGHT REFLECTOR TARGET SILW ARP
HEIGHT REFLECTOR TARGET SILAS TP1
HEIGHT DIFFERENCE SILAS TP1 TO
SILW ARP (ANTENNA REFERENCE POINT
TOP OF BRACKET)
REFLECTOR TARGET
SILAS TP1
(TOP OF RAIL)
BACKSIGHT
B
A
C
E
BOTTOM OF BRIDGE
CENTERLINE BRIDGE
BOTTOM OF BRIDGE


SILAS PEARLMAN BRIDGE
Charleston, South Carolina
SILW - North Side Center Span
HEIGHT DIFFERENCE SILAS TP1 TO SILAS 1999
TRIGONOMETRIC HEIGHT MEASUREMENTS
BACKSIGHT
REFLECTOR TARGET AT SILAS TP1
RIGHT TRIANGLE ABC DEFINED
SIDE BC IS HEIGHT DIFFERENCE
BETWEEN TOTAL STATION AND
REFLECTOR TARGET.
FORESIGHT
REFLECTOR TARGET AT SILAS 1999
RIGHT TRIANGLE ADE DEFINED
SIDE DE IS HEIGHT DIFFERENCE
BETWEEN TOTAL STATION AND
REFLECTOR TARGET
HEIGHT DIFFERENCE BETWEEN SILAS TP1
REFLECTOR TARGET AND SILAS 1999
REFLECTOR TARGET = FORESIGHT - BACKSIGHT
SINCE BOTH THE BACKSIGHT AND FORESIGHT
REFLECTOR TARGETS WERE MOUNTED ON
EQUAL HEIGHT 2 FT POLES, THE HEIGHT
DIFFERENCE BETWEEN SILAS TP1 AND SILAS 1999
IS THE SAME AS THE HEIGHT DIFFERENCE
BETWEEN THE REFLECTOR TARGETS.
BACKSIGHT
FORESIGHT
SILAS 1999
BOTTOM OF BRIDGE
CENTERLINE BRIDGE
BOTTOM OF BRIDGE

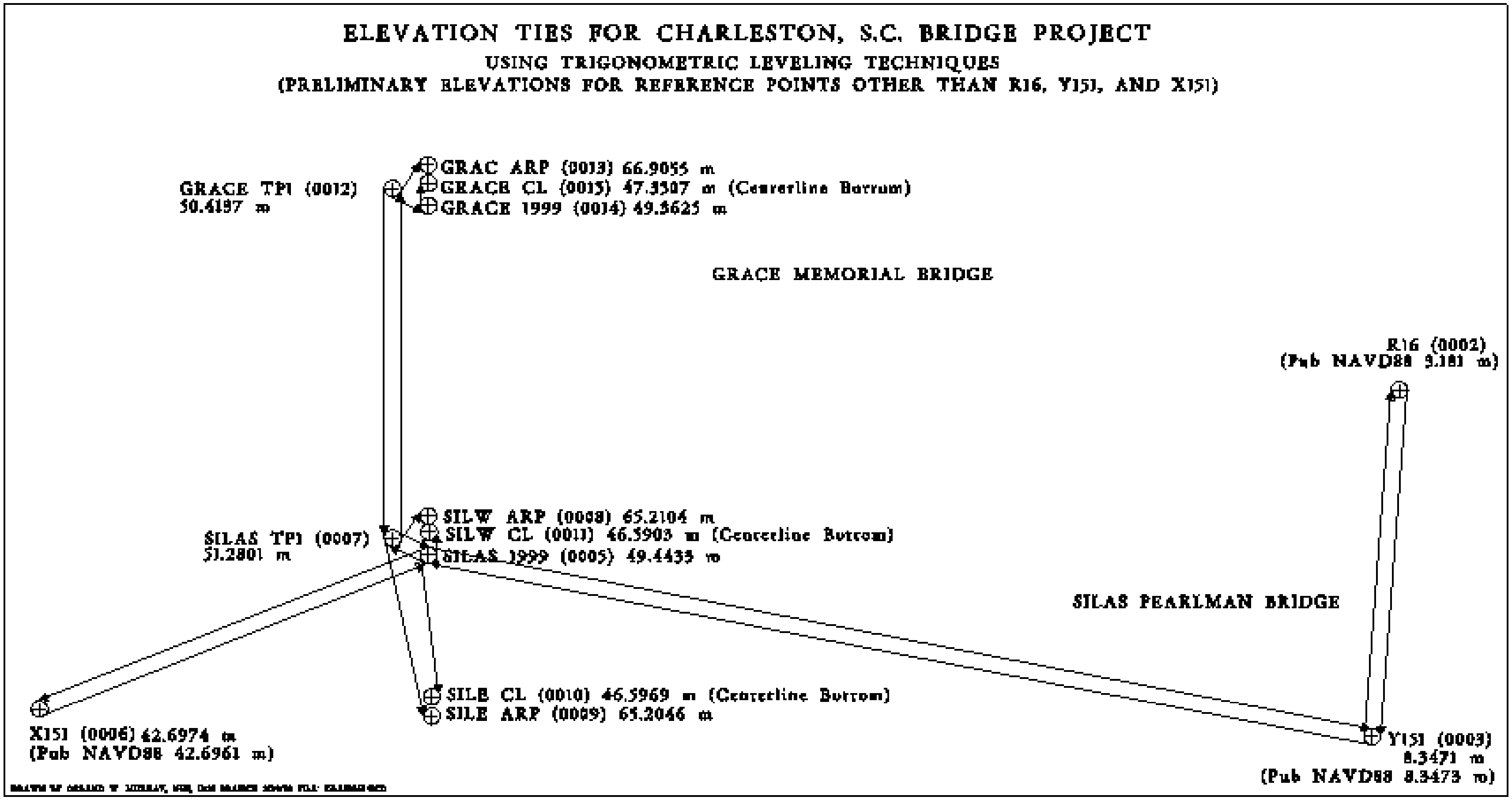

SILAS PEARLMAN BRIDGE
Charleston, South Carolina
SILW - North Side Center Span
HEIGHT DIFFERENCE SILAS 1999 TO
CENTERLINE BOTTOM OF BRIDGE
TOTAL STATION
BACKSIGHT
FORESIGHT
BOTTOM OF BRIDGE
CENTERLINE BRIDGE
RIVETS
BOTTOM BRIDGE BEAM
BOTTOM OF BRIDGE

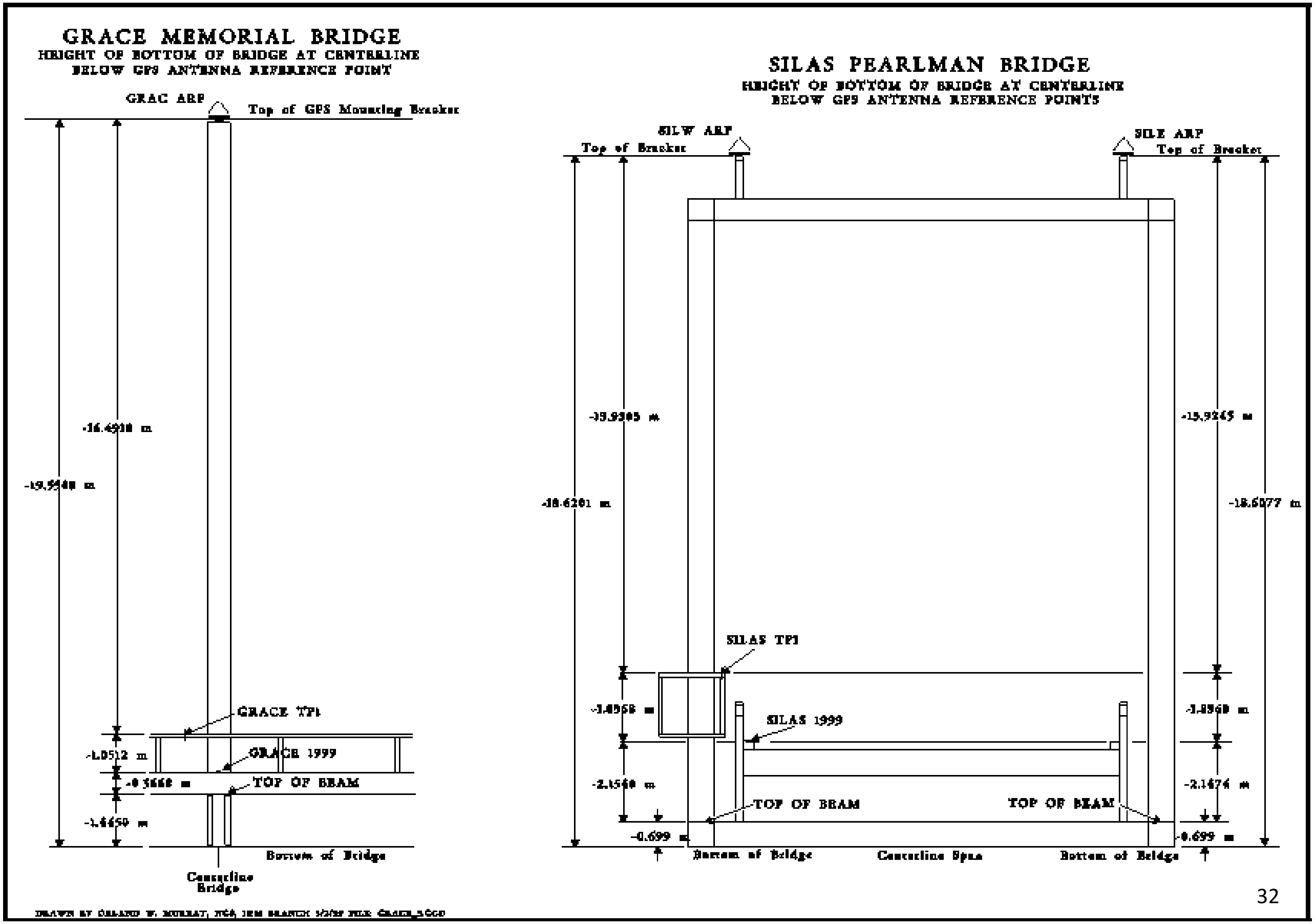
ATTACHMENT B

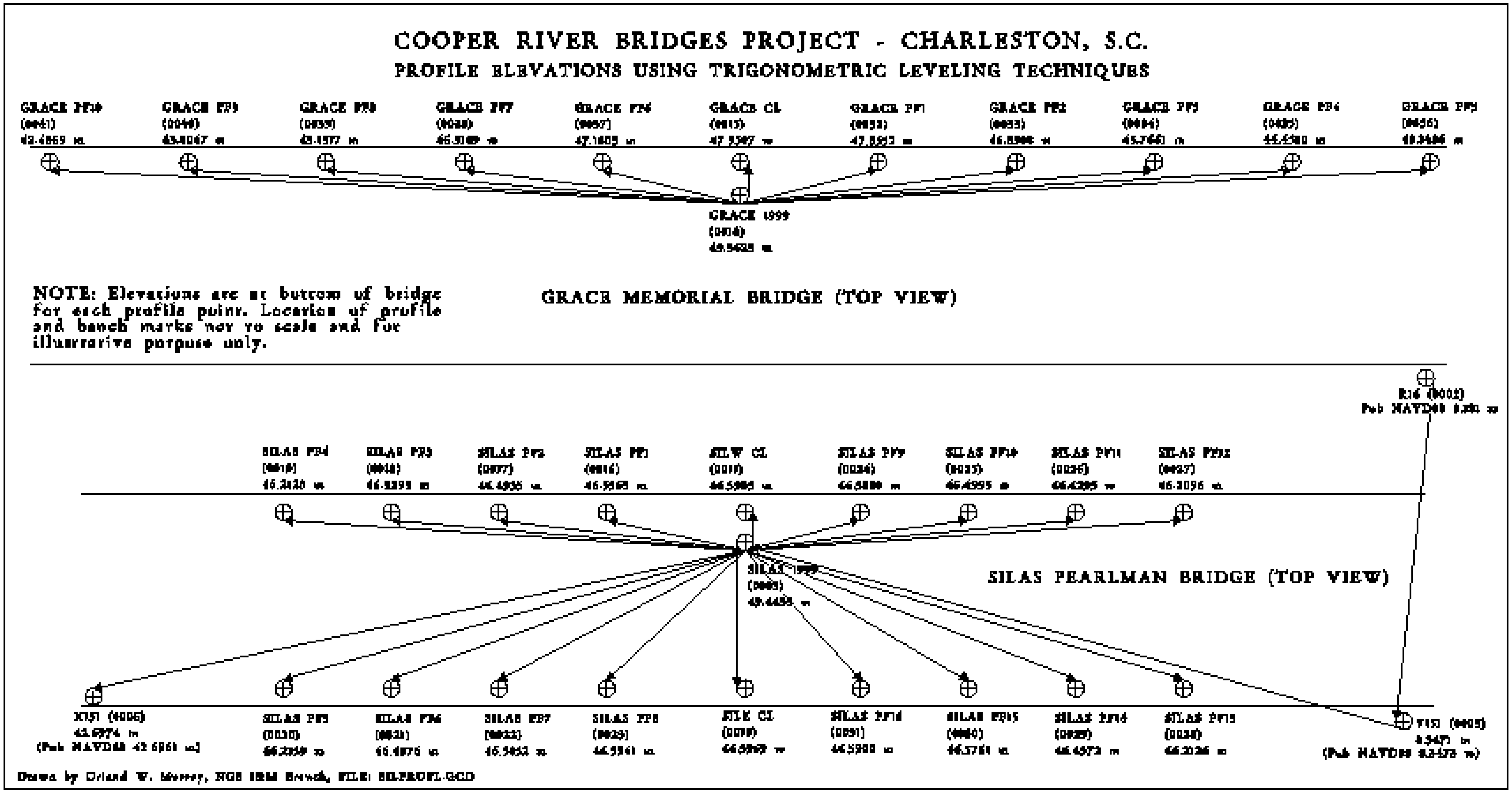
Project Sketches
Height Diagrams
Profile Diagrams

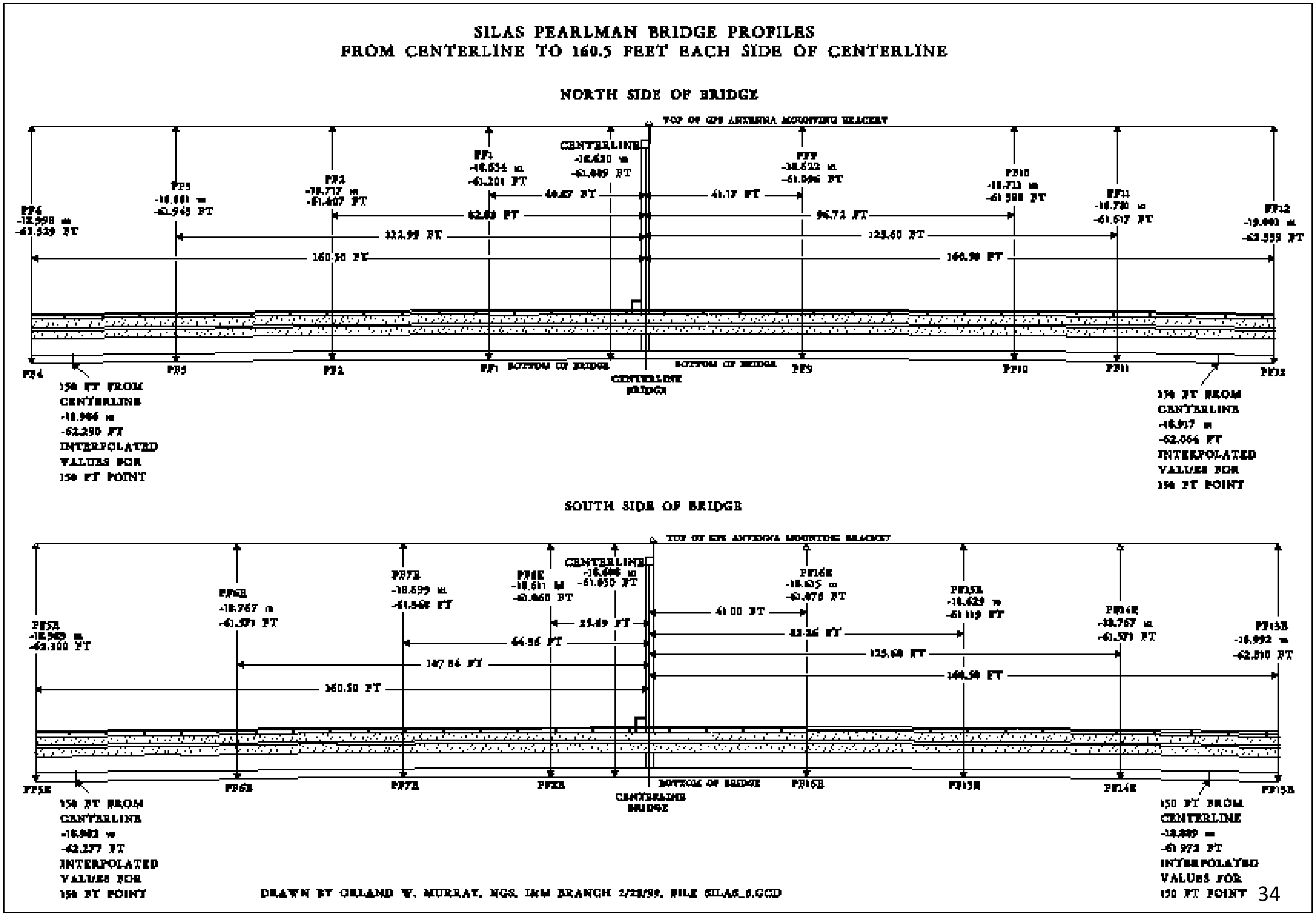


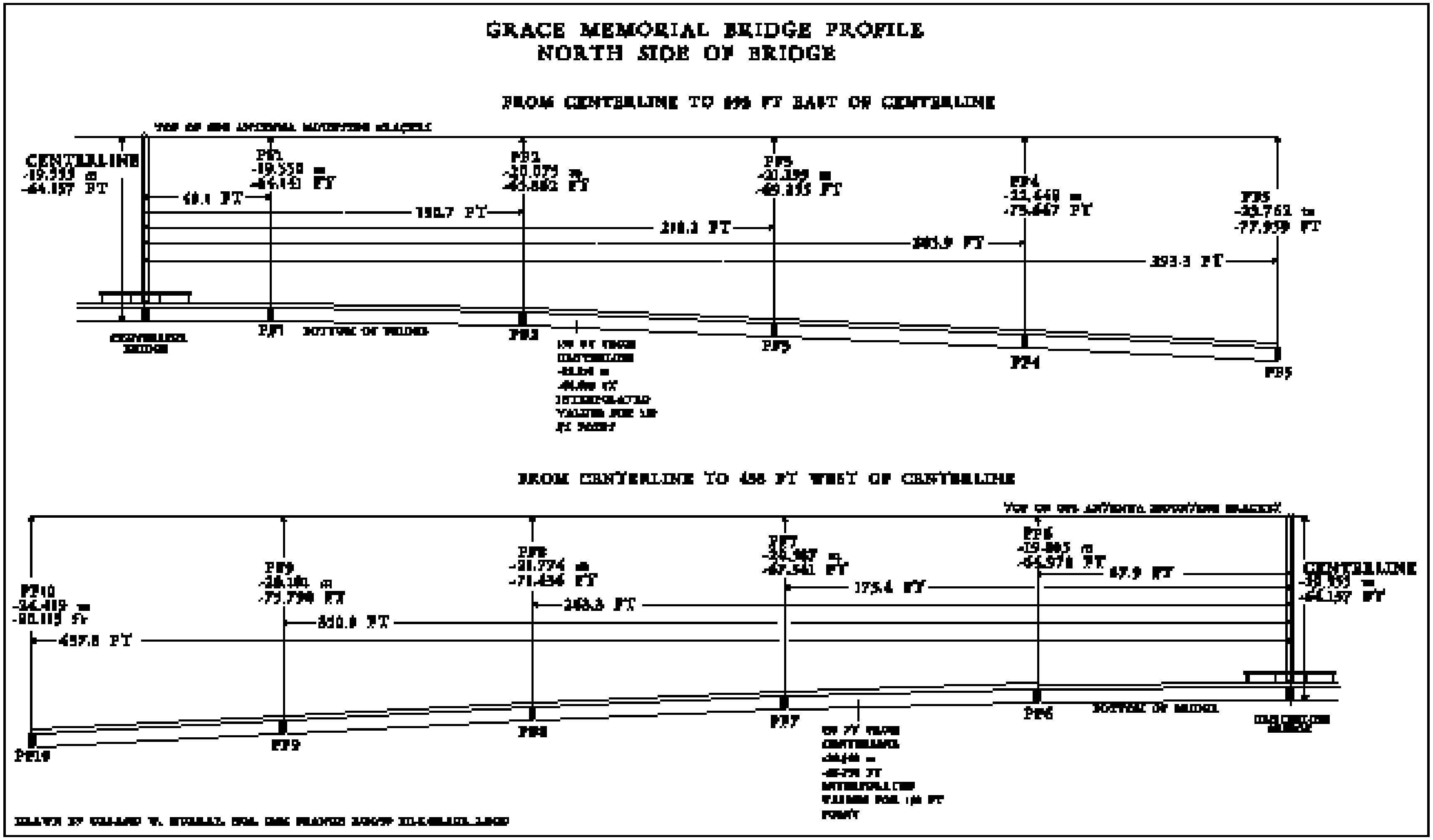
SILAS PEARLMAN BRIDGE - CHARLESTON, S.C.
South Side Bottom - Center Span
NAVD88 - Orthometric Height
Tidal - Mean High Water (MHW) Height
TOP OF GPS ANTENNA
MOUNTING BRACKET
GPS ANTENNA
HI = -18.608 m
Δh = 62.987 m
BOTTOM OF BRIDGE
CENTERLINE
BRIDGE
BOTTOM OF BRIDGE
= 2,219 + [62.987 - ((-33.195)-(-33.128))]
= 2,219 + 62,994
= 65.219 m
HI = -18.608 m
= 46.603 m or 152.906 Ft
NAVD88 - MHW = -2.04 Ft
= 150.865 Ft.
= 150.865 Ft.
= GPS height of antenna
= Height of the NAVD88 bench mark
= Delta height minus the geoid height differences
HI = Height of the bottom of the bridge to the
top of the antenna mounting bracket or plate
= Height of the bottom of the bridge
MHW = Mean High Water
= Height of the bottom of the bridge above MHW
N = Geoid Height
= 2.219 m
NAVD88 BM
2.219 m
MEAN HIGH WATER


ELEVATION TIES FOR CHARLESTON, S.C. BRIDGE PROJECT
USING TRIGONOMETRIC LEVELING TECHNIQUES
(PRELIMINARY ELEVATIONS FOR REFERENCE POINTS OTHER THAN R16, Y151, AND X151)
GRAC ARP (0013) 66.9055 m
GRACE TP1 (0012)
50.4197 m
GRACE CL (0015) 47.3507 m (Centerline Bottom)
GRACE 1999 (0014) 49.5625 m
GRACE MEMORIAL BRIDGE
R16 (0002)
(Pub NAVD88 3.181 m)
SILW ARP (0008) 65.2104 m
SILAS TP1 (0007)
51.2801 m
SILW CL (0011) 46.5903 m (Centerline Bottom)
SILAS 1999 (0005) 49.4435 m
SILAS PEARLMAN BRIDGE
SILE CL (0010) 46.5969 m (Centerline Bottom)
SILE ARP (0009) 65.2046 m
X151 (0006) 42.6974 m
(Pub NAVD88 42.6961 m)
Y151 (0003)
8.3471 m
(Pub NAVD88 8.3473 m)


GRACE MEMORIAL BRIDGE
HEIGHT OF BOTTOM OF BRIDGE AT CENTERLINE
BELOW GPS ANTENNA REFERENCE POINT
GRAC ARP
Top of GPS Mounting Bracket
-16.4910 m
-19.5540 m
GRACE TP1
-1.0512 m
GRACE 1999
-0.3668 m
TOP OF BEAM
-1.6450 m
Bottom of Bridge
Centerline
Bridge
SILAS PEARLMAN BRIDGE
HEIGHT OF BOTTOM OF BRIDGE AT CENTERLINE
BELOW GPS ANTENNA REFERENCE POINTS
SILW ARP
Top of Bracket
SILE ARP
Top of Bracket
-15.9305 m
-18.6201 m
-15.9245 m
-18.6077 m
SILAS TP1
-1.8958 m
SILAS 1999
-1.8960 m
-2.1540 m
-2.1474 m
TOP OF BEAM
TOP OF BEAM
-0.699 m
-0.699 m
Bottom of Bridge
Centerline Span
Bottom of Bridge


COOPER RIVER BRIDGES PROJECT - CHARLESTON, S.C.
PROFILE ELEVATIONS USING TRIGONOMETRIC LEVELING TECHNIQUES
GRACE 1999
NOTE: Elevations are at bottom of bridge for each profile point. Location of profile and bench marks not to scale and for illustrative purpose only.
GRACE MEMORIAL BRIDGE (TOP VIEW)
SILAS PEARLMAN BRIDGE (TOP VIEW)
SILAS 1999


SILAS PEARLMAN BRIDGE PROFILES
FROM CENTERLINE TO 160.5 FEET EACH SIDE OF CENTERLINE
NORTH SIDE OF BRIDGE
CENTERLINE
160.50 FT
BOTTOM OF BRIDGE
CENTERLINE BRIDGE
150 FT FROM CENTERLINE
INTERPOLATED VALUES FOR 150 FT POINT
SOUTH SIDE OF BRIDGE
160.50 FT
125.60 FT
41.00 FT
BOTTOM OF BRIDGE
CENTERLINE BRIDGE
150 FT FROM CENTERLINE
INTERPOLATED VALUES FOR 150 FT POINT


GRACE MEMORIAL BRIDGE PROFILE
NORTH SIDE OF BRIDGE
CENTERLINE
-64.157 FT
-77.959 FT
393.3 FT
CENTERLINE

ATTACHMENT C

Equipment List

Equipment List for Charleston Bridge Project

1 TC2002 Total Station Sn:359817 NOAA:529697
4 Instrument Batteries GEB64
1 Battery Saver 3 Quick Charger and adaptors
1 Standard Leica battery charger for both TC2002 and NA3003 batteries
1 GTS-700 Total Station Sn:KE0136 NOAA:529647 Battery Charger in case
1 GTS-700 Battery extra
1 Laptop Computor Sn:5021 NOAA:493813 Mod#: 48431
1 Metal Scale 300 mm
1 Thermistor temperature probe and display unit
2 Tribrachs
5 Tribrach Adaptors
1 Alti-plus digital barometer
1 Psychrometer
1 NA3003 Digital Level Sn:92430 NOAA:529526
2 Leveling Rod 3-meter invar bar-coded
Sn:27236 NOAA:529636
Sn:27229 NOAA:529635
1 60 CM invar strip
1 Small Kern Collimator
2 Trig Leveling Targets
2 GPS magnetic antenna mounts (Dave Crump's) Note: Height to top of yellow surface 61.0 mm
2 SECO Trig-leveling poles
Various adaptors for targets (bayonets, 5/8x11 adaptors)
2 Two meter GPS poles

Range pole sets (2-15 ft and parts, 1ft , 2 ft, Seco 5 m adjustable,bubbles, braces and clamps)
4 Peanut prism targets (0 or -30.0 mm constants)
2 Tapes 30 meter (standardized and non)
Various mounting magnets (big and little)
6 Radios (two-way walkie talkie)
CBL#3 Sn : 651ARU0210
CBL#2 Sn : 65IARU0209
Corbin Sn: 651ARU0212
Corbin Sn: 651ARU0213 Corbin Sn: 651ARU0214
Corbin Sn: 651ARU0215
4 Radio chargers
1 Umbrella
Rope and haulup bag
Various Tools (hammer, chisels, wrenches, C-clamps, tie straps,etc.)
Mark and mark setting material (epoxy)
Various angle iron pieces to mount targets
1 Slip-leg Tripod
1 T-3 Fixed leg
1 Level tripod fixed leg
Recording forms and field books
Bridge Diagrams and notes
1 HP-41 Calculator
1 HP-200LX handheld computer
Duct tape
Standard batteries (D, C, AA etc.)
Cameras
Safety Vests
Binoculars
Flashlights

2 Tripod Holders
2 Leveling turning pins and hammer
2 12 volt Flashing Warning Lights